

RESOLUTION ENHANCEMENT OF HALF-TONED BLACK DATA TRANSMITTED WITH COLOR DATA

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BACKGROUND OF THE INVENTION

5 Field of the Invention

This invention relates generally to printing images defined by electrical signals and, more particularly, to the enhancement of black images when rendered at a resolution (e.g., 300 dpi) of color images but printed by a higher resolution print cartridge (e.g., 600 dpi).

10 Description of the Related Art

In some printer systems, an image can contain color regions, isolated black regions, and regions with adjacent black and color regions. The black regions can, for example, include black letters within a color region. Some printers are able to render (process) isolated black text at a resolution of 600 dots per inch (dpi) and
15 print the black dots using a 600 dpi print cartridge. In this case, the resolution of the black text is truly at a 600 dpi resolution.

It is common for such printers to only render color images at a resolution of 300 dpi, upscale the data, and then halftone the image at this higher resolution data for printing with higher resolution capable print systems (higher dpi print cartridges
20 do not increase the resolution of dots rendered at a lower resolution). Rendering the color pixels at 300 dpi is much less processor intensive than rendering the color pixels at 600 dpi. There is little loss in image quality in this method, since most practical color images are stored at less than 300 dpi. There is a slight loss in color text sharpness in this method. It is important to provide a high resolution for black
25 ink due to its high contrast with white paper, so printing black, especially text, at the lower resolution may be objectionable. The term "upscaled" in this application

refers to doubling the data in both axis – a very simple 2x expansion vertically and horizontally (or could it be described as replicating horizontally and vertically).

In certain situations, such as where black pixels are adjacent color pixels, the black image is rendered at the same “lower” resolution (e.g., 300 dpi) of the color image. In other words, for those areas where the black regions are adjacent color regions, the mixed region is encoded in the 300 dpi format. This is sometimes referred to as the black pixels being processed through the color pipeline.

The lower resolution black regions (e.g., text), rendered with the color at the color resolution, is upscaled with the color data, and then merged with the higher resolution (600 dpi) black data, such as isolated text. The resulting data-doubled text is referred to as “chunky” text. An example of chunky text can be found in Fig. 1A. For comparison, Fig. 1B is an example of script that has been rendered at 600 dpi.

Thus, even though the printer mechanism has the capability to print black pixels at 600 dpi, the black regions rendered at 300 dpi along with the color regions remain encoded for 300 dpi, and simply doubling the pixels provides no apparent increased resolution.

Additionally, some systems may choose to render an entire page at a lower resolution, say 300 dpi, upscale the image to 600 dpi, and then halftone this image at 600 dpi. The image will render much faster at the lower resolution of 300 dpi, and the halftoning of the upscaled data will result in smooth transitions between colors, and be nearly indistinguishable from 600 dpi rendering. Color text will be compromised in this mode. However, when true 300 dpi black text is upscaled and halftoned at 600 dpi, the pixel replication of the true black data still exhibits low resolution edge characteristics.

Systems for smoothing jagged edges of text are known; however, such systems do not address the situation where black images are rendered by the color

pipeline. One smoothing algorithm is referred to as a TES (thermal inkjet edge smoothing) algorithm, described in U.S. Patent 5,650,858, entitled "Pixel Image Edge-Smoothing Method and System," invented by Mark D. Lund, assigned to the assignee of the present invention and incorporated by reference herein. There is a
5 need for an apparatus and an associated method having the feature that black image regions rendered along with color image regions are resolution-enhanced and printed with a resolution higher than that of the color image regions. Another desired feature of the apparatus and the associated method is the representation of the data groups used in processing the black pixel images in word-length data groups.

10 SUMMARY

The aforementioned and other features are accomplished, according to one embodiment of the present invention, by the following method. The black and color pixels being rendered at the color resolution (e.g., 300 dpi) are upsampled by simple pixel replication and halftoned, causing the black data to be upsampled to 600 dpi.

15 Black data, such as isolated text, rendered at the higher resolution (600 dpi) is then merged with the upsampled data. The merged black pixels are separated from the color pixels.

A target pixel group in the black image is selected. If the portion of the black image being processed was previously rendered at the color resolution, then the
20 target pixel group represents a single pixel in the rendered 300 dpi image (i.e., four 600 dpi pixels in the group). Then, a window of neighboring pixels in the 600 dpi image surrounding the target group is chosen. In one embodiment, the window is selected to permit a row of pixels within the chosen window to be represented by word-size data groups of 16 bits or less. In one embodiment, the window is an array
25 of a maximum of 13x13 pixels.

The pixels within the chosen window are applied to a logic array that inputs pixel patterns and computes modified target pixels, if necessary, to provide an optimal image subject to a number of (sometimes conflicting) constraints. The

values of the pixels in the target group, after processing by the logic array, are enhanced resolution pixel values, and the processed pixel group is stored in place of the target group. The process is continued until all of the pixels comprising the original image have been processed. Typically, those pixels in the black image rendered at the higher resolution will not be changed by the logic array, but they still may be changed depending on the "programming" of the logic array.

The processed black pixels are then printed by a 600 dpi printhead. Thus, certain black pixels on the page will have been rendered at 300 dpi and some will have been rendered at 600 dpi, but the resolutions will appear similar. The color portion of the image is printed at its rendered (non-enhanced) print resolution, such as at 300 dpi. The invention applies to any resolution.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention may be better understood, and its numerous objects, features, and advantages made apparent to those skilled in the art by referencing the accompanying drawings.

Figure 1A illustrates chunky text, which was encoded (rendered) at a resolution of 300 dpi and then upscaled to match the input size to a 600 dpi grid for printing by a 600 dpi black printhead.

Figure 1B illustrates text rendered at 600 dpi.

Figure 2 is a flowchart illustrating the resolution-enhancement of the pixels of the black regions according to the present invention.

Figure 3A is a representation of a particular logical condition for identifying a 4-pixel 600 dpi resolution pixel group to replace an original 300 dpi resolution pixel when the logical condition is met by a window of pixels.

Figure 3B illustrates the values of the enhanced 600 dpi pixel group when the window of pixels meets the logical condition of Fig. 3A.

Figure 4 is a block diagram of apparatus for generating enhanced pixel values for selected black pixels according to one embodiment of the present invention.

Figure 5 illustrates text which has been algorithmically enhanced from an image rendered at 300 dpi image and printed at 600 dpi using the techniques
5 described herein.

The use of the same reference symbols in different drawings indicates similar or identical items.

DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

Referring to Fig. 2, a flowchart for enhancing the resolution of black regions rendered at a resolution of color regions is shown. In one embodiment, black
10 regions adjacent to color regions of an image are rendered at the same resolution of the color regions (e.g., 300 dpi). Other black regions, such as isolated black text, are rendered at a higher resolution (e.g., 600 dpi). In the example below, it is assumed that the black and color pixels are rendered at the color resolution of 300 dpi, and the
15 invention enhances the black data to have a resolution of 600 dpi image, although the invention applies to any resolution. Any black data rendered at the 600 dpi resolution does not require any enhancement.

In step 10, original pixels are generated by, for example, a personal computer, and processed (rendered) so as to be in the printer color space. The black
20 regions of the image adjacent to color regions are rendered at the resolution of the color regions.

In step 11, isolated black regions, such as text, are rendered at the higher resolution.

In step 12, the upscaling and halftoning algorithms are performed on the
25 black and color pixels from step 10. For the color pixels, the halftoning algorithm identifies discrete color dots to be printed and effectively distributes the color error

to neighboring pixels. The halftoning causes the perceived color in an area on the medium to closely match the desired color. However, when the upscaling and halftoning are performed on the true black pixels, there is no distribution of error since the original dots are either black or white. The upscaling algorithm converts the 300 dpi black pixels to 600 dpi black pixels. The 600 dpi is chosen because that is the dpi resolution of the black printhead in one embodiment. The result of the upscaling step is that each of the transmitted black and white pixels rendered at 300 dpi is duplicated to form a pixel field at a resolution of 600 dpi (i.e., each original pixel is duplicated four times). This step can be accomplished by remapping the pixels in an input buffer or by a pixel relabeling step. This 600 dpi pixel field has not yet been enhanced. The dpi can be greater than 600 dpi (e.g., 1200 dpi, 2400 dpi, etc.), or the dpi in the vertical and horizontal directions may be different.

In step 14, any black pixels, such as isolated text, rendered at 600 dpi is merged with the halftoned pixels.

In step 16, the black pixels are separated from the color pixels. This simply diverts the processing path of the color pixels away from the resolution enhancement process for the black pixels, and allows the color pixels to be processed in any conventional manner (step 17).

In step 18, assuming the black pixels being processed were rendered at 300 dpi, an original 300 dpi pixel (a target pixel), as now represented by a target group of four unprocessed pixels, is selected for processing in order to generate four enhanced, high resolution pixels.

In step 20, a pre-established neighborhood or window of 600 dpi unprocessed pixels surrounding the target group of four unprocessed pixels is identified. The unprocessed pixels in the window are encoded in a logic signal format, and the encoded logic signals are processed by a logic circuit (e.g., a logic array) in step 22. The logic circuit (described in more detail later) performs logical operations on the pixel window and changes the target pixels if necessary.

In step 24, the four pixel values output from the logic circuit replace the target group of four pixels in the window. These pixel values may be the same as the selected unprocessed pixel values, or the selected unprocessed pixel values can be altered.

5 The processed pixels that replace the selected unprocessed pixels are stored in a print buffer in step 26. The color pixels that have undergone conventional processing are also stored in a print buffer.

10 In step 28, after the print buffer has stored a certain number of pixels, the pixels stored in the print buffer are forwarded to the print engine. The print engine generates the timed printhead energization signals for printing the black portion of an image at the 600 dpi resolution. Since color pixels are not enhanced, the color pixels are still printed at the halftoning resolution.

 In step 29, the procedure returns to step 18 until all of the pixels have been printed.

15 Referring to Fig. 3A and Fig. 3B, an example of the use of the logic circuit to provide an enhanced 600 dpi pixel image from a 300 dpi pixel image is illustrated. Fig. 3A is a representation of a logical condition 30 met by the pixel window. The heavier grid lines 31 define the original 300 dpi pixel areas. The original pixels in the 300 dpi format are shown by, for example, pixel groups 32, 33, and 35. The ^{darker} solid areas define the black pixels 33. The ^{lighter} lined areas denote the white pixels 32. The blank areas denote the "don't care" pixels 34, which can be either black pixels or white pixels. In order to achieve a 600 dpi pixel resolution, as indicated above, each 300 dpi pixel is divided into four pixels. The logical condition 30 in Fig. 3A illustrates the division of the 300 dpi pixels by the lighter grid lines 36. The logical condition 30 takes into account the neighborhood or window surrounding the target pixel group 35.

20 A

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Shown in Fig. 3B are the four processed pixels associated with the logical condition 30 of Fig. 3A that replace the four pixels in the target group 35. When the logical condition 30 is met, the pixel values associated with the logical condition 30 replace the values of the pixels in the target group. In Fig. 3B, for example, the processed black pixels labeled P1, P2, and P4 replace corresponding unprocessed white pixels in the target group 35. The processed pixel P8 of Fig. 3B has a value that is unchanged from the value of the corresponding unprocessed pixel of the target group 35.

The number of different logical conditions programmed into the logic circuit, the particular logical conditions, and the values of the processed pixels are established empirically by determining, from resulting images, which logical conditions and associated processed pixel values provide the highest quality, pseudo-600 dpi image. These logical conditions and processed pixel values accommodate the often conflicting goals of: preserving the image stroke weight to the extent possible; minimizing shifts in input pixel image features, and when shifting an image is necessary, shifting the image features minimally in the same direction; smoothing character fonts in such a manner that curves, intersections, endpoints and serifs are accurately reproduced; and preserving halftones of graphic or pictorial images. For purposes of illustrating the present invention, the logical condition set found in U.S. Patent 5,650,858, incorporated herein by reference, may be used. It will be appreciated that the window of neighboring pixels used in the described embodiment of the present invention is larger than the window found in the '858 Patent.

The logical conditions may be represented by simple logic equations. An example of a logical condition defined by a Boolean equation is given by following equation, the equation defining the pixel pattern (logical condition T39) of Fig. 3A.

$$\begin{aligned} T39 = & \neg H1 \cap \neg I1 \cap \neg H2 \cap \neg I2 \cap \neg F3 \cap \neg G3 \cap J3 \cap K3 \cap \neg F4 \cap \neg G4 \\ & \cap J4 \cap K4 \cap \neg D5 \cap \neg E5 \cap \neg F5 \cap \neg G5 \cap H5 \cap I5 \cap \neg D6 \cap \neg E6 \end{aligned}$$

$$\begin{aligned} & \neg F6 \wedge \neg G6 \wedge H6 \wedge I6 \wedge \neg B7 \wedge \neg C7 \wedge \neg D7 \wedge \neg E7 \wedge \neg F7 \wedge \\ & \neg G7 \wedge H7 \wedge I7 \wedge \neg B8 \wedge \neg C8 \wedge \neg D8 \wedge \neg E8 \wedge \neg F8 \wedge \neg G8 \wedge H8 \\ & \wedge I8 \wedge \neg B9 \wedge \neg C9 \wedge D9 \wedge E9 \wedge F9 \wedge G9 \wedge \neg B10 \wedge \neg C10 \wedge D10 \\ & \wedge E10 \wedge F10 \wedge G10 \wedge B11 \wedge C11 \wedge B12 \wedge C12 \end{aligned}$$

- 5 The \neg symbol before an index of the coordinates of a pixel indicates a white unprocessed pixel at that position and a white pixel in the logical condition T39. No symbol before an index indicates a black unprocessed pixel at that position and a black pixel in the logical condition T39. The \wedge symbol represents a logical AND operation. The positions not identified are “don’t care” positions in the window.
- 10 For example, matching a pixel window with the T39 logical condition requires a white pixel in positions H1, I1, H2, I2, F3, G3, F4, etc., and a black pixel in positions J3, K3, etc.

- In addition to the logical equations of the form shown above used to determine if the unprocessed pixels meet a logical condition, a second group of
- 15 logical equations is needed to generate the processed pixel values for the target group pixels. These simple logical equations determine whether the value of each of the pixels in the target group changes or remains the same. The logic equations are reflected in Fig. 3B.

- As indicated above, the pixels P1, P2, and P4 change value, while pixel P8
- 20 retains the same value, as a result of the logic processing. The change of the value of the pixels can be represented by $\text{Change_P1} = \dots \cup \text{T39} \cup \dots$; $\text{Change_P2} = \dots \cup \text{T39} \cup \dots$; and $\text{Change_P4} = \dots \cup \text{T39} \cup \dots$. No equation is provided for P8 because the P8 pixel does not change as a result of the matching of the window of pixels with the T39 logical condition.

- 25 The logical conditions used in one embodiment of the invention enable a window of only a 13 x 13 pixel array. Such sizes can use a single word (16 bits) to convey a row of pixels in the window. Any size equal to or less than a word size offers great advantages in circuit complexity and speed.

Referring to Fig. 4, a functional block diagram of the printer/controller apparatus according to one embodiment of the present invention is shown. The color pixels and certain black pixels rendered at 300 dpi are applied to an upscaling and halftoning algorithm 40, previously described. The upscaling and halftoning of the black pixels upscales the 300 dpi black pixels to create a 600 dpi black pixel pattern. Upscaling and halftoning are also performed on the color pixels, as previously described with respect to Fig. 2, but since the color processing is conventional, it is not described in detail. The upscaling and halftoning of the color pixels is assumed to also double the color pixels (but not increase the resolution) in order to achieve a desired drop volume of a color dot.

Any "original" 600 dpi black pixel data rendered at 600 dpi is then merged with the output of the halftoning process. Such 600 dpi black pixel data rendered at 600 dpi would typically include black text separated from any color image. The merging may be accomplished with an OR gate 42. Merging can be accomplished at various points along the process path for the black pixels.

The black pixels are separated from the color pixels so as to be processed by different paths. In one embodiment, the black (K) and C, M, and Y data reside on different memory "planes," and the black pixel selection circuit 44 simply diverts the black data to be processed along the upper path. The term "selection" applies to both cases.

The black pixels are then mapped in a buffer 48.

Pixels in buffer 48 forming the target pixels and the neighborhood of pixels are addressed and applied to a logic circuit 50. In the embodiment of a 13x13 pixel window, buffer 48 applies 169 pixel values on lines 49 to logic circuit 50. Logic circuit 50 is a conventional logic array that contains all the logical conditions and the logic that modifies the target pixels. As a result of this logical process, the target group of pixels is replaced with processed values (e.g., 4 values on lines 51) and stored in the print buffer 52. Any originally rendered 600 dpi black pixel data (e.g.,

conventional text) may or may not be changed by the logic circuit 50. After a pixel image has been assembled in the print buffer 52, at the appropriate time, the image is applied to the print engine, and the black portion of the image is printed by the black printhead 54.

5 The color pixels are concurrently processed in a conventional manner by the color print engine 56 (including buffer, timing circuits, etc.) and printed by printheads 58.

10 The logic operation can be implemented in hardware, firmware, software, or combinations thereof without departing from the scope of the invention. Those skilled in the art can readily implement the invention using commercially available hardware.

 An example of a color printer that may employ the present invention is found in U.S. Patent No. 5,648,806, assigned to Hewlett-Packard and incorporated herein by reference.

15 Fig. 5 is a magnified view of text rendered at 300 dpi but enhanced to 600 dpi using the present invention. The logical conditions of the described embodiment use a 13x13 window. By using a 13x13 pixel matrix, a line (or column) of the image can be represent by a word-length group of binary bits (16 bits), the word being particularly convenient for use in processing apparatus.

20 Those skilled in the art will be able to implement the devices disclosed herein without undue experimentation and will understand that the process parameters, materials, dimensions, and sequence of steps are given by way of example only and can be varied to achieve the desired results. Variations and modifications of the embodiments disclosed herein may be made based on the
25 description set forth herein without departing from the spirit and scope of the invention as set forth in the following claims. In particular, the invention has been described with respect to a rendered image pixel resolution of 300 dpi in conjunction

Age	Sex	Height	Weight	Body Mass Index	Waist Circumference	Hip Circumference	Waist-Hip Ratio	Triceps Skinfold Thickness	Biceps Skinfold Thickness	Subscapular Skinfold Thickness	Sum of Four Skinfolds
18	M	175	75	24.5	85	100	0.85	12	10	15	37
19	F	165	60	22.0	75	90	0.83	10	8	12	30
20	M	180	80	24.7	90	110	0.82	15	12	18	45
21	F	170	70	24.1	80	105	0.76	11	9	14	34
22	M	185	85	24.3	95	115	0.83	16	13	19	48
23	F	175	75	24.5	85	100	0.85	12	10	15	37
24	M	190	90	25.0	100	120	0.83	18	15	22	55
25	F	180	80	24.7	90	110	0.82	15	12	18	45
26	M	195	95	25.1	105	125	0.84	19	16	23	58
27	F	185	85	24.3	95	115	0.83	16	13	19	48
28	M	200	100	25.0	110	130	0.85	20	17	24	61
29	F	190	90	25.0	100	120	0.83	18	15	22	55
30	M	205	105	25.4	115	135	0.85	21	18	25	64
31	F	195	95	24.6	105	125	0.84	19	16	23	58
32	M	210	110	25.0	120	140	0.86	22	19	26	67
33	F	200	100	25.0	110	130	0.85	20	17	24	61
34	M	215	115	25.1	125	145	0.86	23	20	27	70
35	F	205	105	25.4	115	135	0.85	21	18	25	64
36	M	220	120	25.0	130	150	0.87	24	21	28	73
37	F	210	110	25.0	120	140	0.86	22	19	26	67
38	M	225	125	25.0	135	155	0.87	25	22	29	76
39	F	215	115	25.1	125	145	0.86	23	20	27	70
40	M	230	130	25.0	140	160	0.88	26	23	30	79
41	F	220	120	25.0	130	150	0.87	24	21	28	73
42	M	235	135	25.0	145	165	0.88	27	24	31	82
43	F	225	125	25.0	135	155	0.87	25	22	29	76
44	M	240	140	25.0	150	170	0.88	28	25	32	85
45	F	230	130	25.0	140	160	0.87	26	23	30	79
46	M	245	145	25.0	155	175	0.88	29	26	33	88
47	F	235	135	25.0	145	165	0.87	27	24	31	82
48	M	250	150	24.0	160	180	0.89	30	27	34	91
49	F	240	140	25.0	150	170	0.87	28	25	32	85
50	M	255	155	23.9	165	185	0.89	31	28	35	94
51	F	245	145	23.9	155	175	0.87	29	26	33	88
52	M	260	160	23.1	170	190	0.90	32	29	36	97
53	F	250	150	24.0	160	180	0.88	30	27	34	91
54	M	265	165	23.0	175						